

Future and Origin of our Universe: Modern View

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Abstract

The existence of a positive and possibly varying Lambda-term opens a much wider field of possibilities for the future of our Universe than it was usually thought before. Definite predictions may be made for finite (though very large) intervals of time only, as well as in other branches of science. In particular, our Universe will continue to expand as far as the Lambda-term remains positive and does not decay to other forms of matter, even if the Universe is closed. Two new effects due to the presence of a constant Lambda-term are discussed: reversal of a sign of the redshift change with time for sufficiently close objects and inaccessibility of sufficiently distant objects in the Universe for us. A number of more distant and speculative possibilities for the future evolution of the Universe is listed including hitting a space-time singularity during an expansion phase. Finally, in fantastically remote future, a part of our Universe surrounding us can become supercurved and superdense due to various quantum-gravitational effects.

This returns us to the past, to the origin of our Universe from a superdense state about 14 Gy ago. According to the inflationary scenario, this state was almost maximally symmetric (de Sitter-like). Though this scenario seems to be sufficient for the explanation of observable properties of the present Universe, and its predictions have been confirmed by observations, the question of the origin of the initial de Sitter (inflationary) state itself remains open. A number of conjectures regarding the very origin of our Universe, ranging from "creation from nothing" to "creation from anything", are discussed.

1 Future of the Universe

It is very popular in cosmology to make definite predictions about infinitely remote future of our Universe. Such predictions may be found in virtually any book on cosmology, popular or sophisticated. Usually they have the following form:

- 1) if the spatial curvature of our Universe is zero or negative, it will *expand eternally*;
- 2) if the spatial curvature is positive, the Universe will stop expanding in future and begin to *recollapse*.

However, it is obvious that any prediction about dynamical evolution of a physical system cannot remain reliable at infinite time. In any branch of science, sure forecasts exist for finite periods of time only, ranging from days in meteorology to millions of years in the Solar system astronomy. So, how can cosmology be an exception from this general rule? Evidently, it can't. Therefore, the conviction that the infinite time prediction given above is reliable

should be no more than an illusion. At present we begin to understand profound reasons for this.

The impossibility to make exact predictions for infinite time evolution in cosmology results from the two reasons: 1) absence of precise knowledge of the present composition of matter in the Universe and future transformations between different kinds of matter; and 2) imprecise knowledge of present initial conditions for spatial inhomogeneities in the Universe. The first reason is vital even for an exactly homogeneous and isotropic Universe, while the second one requires consideration of deviations from isotropy and homogeneity. It was thought for a long time that the second reason is the main source of unpredictability in remote future, but it seems now that the first reason is the most important one.

Recent observational data on supernova explosions at high redshifts $z \sim 1$ obtained by two groups independently [1, 2], as well as numerous previous arguments (see, e.g., [3, 4]), strongly support the existence of a new kind of matter in the Universe which energy density is positive and dominates over energy densities of all previously known forms of matter. This form of matter has a strongly negative pressure and remains unclustered at all scales where gravitational clustering of baryons and cold non-baryonic dark matter is seen. Its gravity results in an acceleration of the expansion of the present Universe: $\ddot{a}(t_0) > 0$, where $a(t)$ is the scale factor of the Friedmann-Robertson-Walker (FRW) isotropic cosmological model with time t measured from the cosmological singularity (the Big Bang) in the past, t_0 is the present moment. In the first approximation, this kind of matter may be described by a constant Lambda-term in gravity equations which was introduced by Einstein. However, a Lambda-term (also called quintessence sometimes) might be slowly varying with time. If so, this will be soon determined from observational data. In particular, if we use the simplest model of a variable Lambda-term borrowed from the inflationary scenario of the early Universe, namely, an effective scalar field ϕ with some self-interaction potential $V(\phi)$ minimally coupled to gravity, then the functional form of $V(\phi)$ may be determined from observational *cosmological functions*: either from the luminosity distance $D_L(z)$ [5, 6], or from the linear density perturbation in the dust-like (cold dark matter (CDM) plus baryon) component of matter in the Universe $\frac{\delta\rho}{\rho}(z)$ [5] (provided the Lambda-term satisfies the weak energy condition $\varepsilon_\Lambda + p_\Lambda \geq 0$).

Should the Lambda-term be always exactly constant, the prediction for the future of the Universe is simple and boring: the Universe will expand forever, energy densities of all kinds of matter apart from the Lambda-term tend to zero exponentially, and the space-time metric locally approaches the de Sitter metric (though globally it has a much more general quasi-de Sitter form, see [7]). Thus, in this case the Universe becomes cold and empty finally. However, this is just the point: we are *not sure* that the Lambda-term will remain exactly the same at all times. And if it changes with time, predictions for remote future of the Universe may appear completely different.

On the other hand, sure forecasts for finite intervals of time are certainly possible in cosmology. Moreover, it is the present high degree of order in the Universe that makes the interval of predictability very large - much larger than in other branches of science. By the way, let us note that according to the inflationary scenario the present regularity of the Universe is a consequence of the fact that the Universe was even more regular - actually, almost maximally symmetric - in the past, during a de Sitter (inflationary) stage. The

curvature at that stage was very high, close to the Planck curvature (though at least five orders of magnitude less near the end of the inflationary stage), in sharp contrast with a very low curvature at the asymptotic quasi-de Sitter stage in future discussed in the previous paragraph. Let me give you an example of such kind of predictions. If we make the following three assumptions: the present Hubble constant $H_0 \geq 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$, the present age of the Universe $t_0 \geq 10 \text{ Gy}$ and the energy density of the Lambda-term is non-negative (and will remain so for the period of time given below), than the Universe will continue its expansion for at least 20 Gy irrespective of the sign of its spatial curvature [8]. At present, we are practically sure from existing observational data that all these three assumptions are correct. Since this interval exceeds the time of active life of main sequence stars (and the Sun, in particular), this estimate is more than sufficient for discussion of the future of the Earth and human civilization.

Derivation of this result goes as follows. If $\varepsilon_\Lambda \geq 0$, the most critical case with respect to recollapse of the Universe in future occurs just when $\varepsilon_\Lambda \equiv 0$ and the Universe is closed ($\mathcal{K} = 1$, positive spatial curvature). The law of the evolution of a closed dust-dominated FRW cosmological model has the following parametric form:

$$a = \frac{1}{2}a_{max}(1 - \cos \eta) , \quad t = \frac{1}{2}a_{max}(\eta - \sin \eta) , \quad 0 \leq \eta \leq 2\pi , \quad (1)$$

where a_{max} is the maximal radius of the Universe (I put $c = 1$ here and below). The parameter η is the conformal time $\eta = \int dt/a(t)$ actually.

The corresponding Hubble parameter is

$$H(t) \equiv \frac{d}{dt} \ln a(t) = \frac{2}{a_{max}} \frac{\sin \eta}{(1 - \cos \eta)^2} . \quad (2)$$

Note that the Hubble constant $H_0 = H(t_0)$. Then it follows from the inequalities for H_0 and t_0 given above that

$$H_0 t_0 = \frac{\sin \eta_0 (\eta_0 - \sin \eta_0)}{(1 - \cos \eta_0)^2} \geq 0.51 , \quad \eta_0 \leq 1.92 \quad (3)$$

where $\eta_0 = \eta(t_0)$. The remaining time of expansion before beginning of recollapse of the Universe which takes place at $\eta = \pi$ in this model is:

$$T_{exp} = \frac{\pi}{2}a_{max} - t_0 = t_0 \frac{\pi - \eta_0 + \sin \eta_0}{\eta_0 - \sin \eta_0} \geq 2.2t_0 \geq 22 \text{ Gy} . \quad (4)$$

Given above was just the rounded form of this inequality. Incidentally, it follows from (3) that the upper limit on the present energy density of dust-like matter in terms of the critical one $\varepsilon_c = 3H_0^2/8\pi G$ is $\Omega_m = \varepsilon_m/\varepsilon_c \leq 1.5$. Of course, presently existing observational data, especially the supernova data mentioned above and data on temperature angular anisotropy $\frac{\Delta T}{T}$ of the cosmic microwave background (CMB) restrict spatial curvature of the Universe even better: $|\Omega_m + \Omega_\Lambda - 1| \leq 0.3$ (see, e.g., the second reference in [2], and [9]).

Still people are interested in more and more remote future. Predictions for this period can be made, of course, but they become less and less reliable with time growth, because we have to base on more and more assumptions. So, speaking about very remote future,

we can at best present a list of some possibilities for future evolution of the Universe. This list, however incomplete it is, shows that real future evolution of the Universe is infinitely complicated and has no boring smooth asymptotic behaviour at $t \rightarrow \infty$.

But before discussing these remote possibilities, let me mention two significantly new effects which arise in the case of a constant Λ -term ($\varepsilon_\Lambda > 0$). From now on, I assume that the Universe is spatially flat ($\mathcal{K} = 0$) for the following reasons: a) no observational data directly point to $\mathcal{K} \neq 0$ at present; b) a spatial curvature of the Universe is strongly bounded as mentioned above, and does not dominate over matter (including both dust-like matter and a Λ -term); c) the simplest inflationary models of the early Universe predict $|\Omega_m + \Omega_\Lambda - 1| \ll 1$; d) for simplicity.

1. Reversal of a sign of \dot{z} for sufficiently close objects.

Let us consider the question how the redshift of a given object changes with time. The present redshift $z \equiv z(t_0)$ is given by the expression

$$1 + z = \frac{a(\eta_0)}{a(\eta_{em})}, \quad \eta_{em} = \eta_0 - r, \quad (5)$$

where r is the constant coordinate (comoving) distance to the object and $\eta_{em} = \eta(t_{em})$ is the moment when the object emitted light observing now. The physical distance to the object is $R = ar$. To find \dot{z} , one has to differentiate (5) with respect to t_0 . If $\Lambda = 0$, then $\dot{z} < 0$ for all z . Moreover, $z(t)$ monotonically decreases with time and tends to 0 as $t \rightarrow \infty$. On the contrary, if $\Lambda > 0$, $z(t)$ stops decreasing at some moment and then begin to increase due to an acceleration of the Universe in the Λ -dominated regime. As a result, $\dot{z} > 0$ if $z < z_c$ at the present time. The value z_c for which $\dot{z}_c(t_0) = 0$ (so \dot{z} considered as a function of z for given the $t = t_0$ changes its sign) is determined from the equation:

$$\dot{a}(t_0) = \dot{a}(t_{em}(z_c)), \quad \eta_{em}(z_c) = \eta_0 - r(z_c). \quad (6)$$

If the Universe is flat, then this equation reduces to the algebraic equation

$$(1 + z_c) \left(\Omega_m + \frac{1 - \Omega_m}{(1 + z_c)^3} \right) = 1. \quad (7)$$

In particular, $z_c = 2.09$ if $\Omega_m = 0.3$ which is the best fit to the supernova data [1, 2]. Note that z_c decreases with increasing Ω_m . This effect may be even directly observed in future, though not too soon because measuring \dot{z} represents a formidable task (see the discussion of problems arising in [10]).

2. Loss of possibility to reach distant objects.

The existence of a constant $\Lambda > 0$ leads to the appearance of the future event horizon (as in the de Sitter space-time). This means that looking at sufficiently remote galaxies with $z > z_{eh}$ at the present time, we can neither reach them physically in an arbitrary long time period, nor even send a message to intelligent beings in them (supposing that such exist or will appear in future) saying “we are!”. In other words, the coordinate volume of space

which our civilization may affect is finite. Its border is given by $r_{eh} = \eta(t = \infty) - \eta_0$. The redshift $z_{eh}(r_{eh}, \Omega_m)$ can be found from the equation

$$\int_1^{1+z_{eh}} \frac{dx}{\sqrt{1 - \Omega_m + \Omega_m x^3}} = \int_0^1 \frac{dx}{\sqrt{1 - \Omega_m + \Omega_m x^3}} \quad (8)$$

(both sides of this equation are equal to $R_{eh}H_0 = a(t_0)r_{eh}H_0$). If $\Omega_m = 0.3$, then $z_{eh} = 1.80$ (note that z_{eh} grows with Ω_m reaching infinity for $\Omega_m = 1$). This is not much, we see many galaxies and quasars with larger redshifts. So, all of them are inaccessible for us. Another similar effect was recently considered in [11].

Now we return to long-time predictions. The standard one usually presented refers to the case of a constant $\Lambda > 0$. Then, as was already mentioned above, the Universe will expand infinitely for any sign of its spatial curvature. It quickly approaches the de Sitter state with $H = H_\infty = \sqrt{\Lambda/3} = H_0\sqrt{1 - \Omega_m}$. So, this scenario may be called “inflation in future”. Matter density $\varepsilon_m \propto a^{-3}(t) \rightarrow 0$ while density perturbations $\delta\varepsilon_m/\varepsilon_m \rightarrow const$ if they are still in the linear regime now. Circumstantially, CMB multipole angular anisotropies $(\Delta T/T)_l$, in particular the quadrupole one, freeze at some constant values, too (see the first reference in [3]). On the other hand, gravitationally bound systems which physical size is $R < 10h^{-1}$ Mpc at present (our Galaxy, in particular) will remain bound, at least as far as classical gravity is concerned (here $h = H_0/100 \text{ km s}^{-1} \text{ Mpc}^{-1}$). So, islands of galaxies will remain in the ever expanding and becoming more and more vacuum-like on average Universe.

However, this is not the only possibility for a future fate of the Universe even at the classical level, and probably not the correct one at all if quantum-gravitational effects are taken into account. A number of possible alternatives is presented below.

1. Decay of Λ in future.

If a Λ -term is unstable and decays faster than a^{-2} (i.e., $\varepsilon_\Lambda a^2 \rightarrow 0$ at $t \rightarrow \infty$), then recollapse of some parts of the Universe becomes possible due to existing inhomogeneities even if $\mathcal{K} = 0$. A Λ -term may decay with time, e.g., in the simplest scalar field model mentioned above if $V(\phi)$ decreases sufficiently fast with growth of $a(t)$. At present, the Λ -term is changing rather slowly, if at all. If we assume for simplicity that its pressure $p_\Lambda = k\varepsilon_\Lambda$, $k = const$, then it follows from observational data that $k < -0.6$ (see, e.g., [12]). Since $\varepsilon_\Lambda \propto a^{-3(1+k)}$ in this case, this corresponds to ε_Λ decaying less rapidly than $a^{-1.2}$ at present. However, this behaviour may change in future.

2. Collision with a null singularity.

There exists a rather unpleasant possibility that our future world line will cross a real space-time singularity with infinite values of the Riemann tensor (though its scalar invariants are less singular and may even remain finite sometimes) concentrated at a null hypersurface. So, this singularity may be called a gravitational shock wave with an infinite amplitude. It was conjectured that such singularities should arise along Cauchy horizons inside rotating or charged black holes [13], and it has been shown that this really occurs in some simplified cases (see [14] for the most recent treatment).

It is not clear at present if this collision is deadly to an intelligent life. However, it is certainly fatal for our ability to predict future of our Universe since any classical extension

of space-time beyond such a singularity is non-unique. The most unpleasant is the fact that an intelligent being cannot even forecast this event until the shock wave hits him/her. Fortunately, this possibility seems to be rather improbable since it requires a very specific global space-time structure of the Universe (namely, the existence of a Cauchy horizon intersecting our future light cone). However, I cannot exclude it completely basing on our present knowledge.

3. Formation of a classical space-like curvature singularity during expansion.

To hit a real space-time singularity with infinite invariants of the Riemann tensor, it is not necessary to have an isotropic recollapse first. Such a singularity may also occur as a result of sudden growth of anisotropy and inhomogeneity at some moment during expansion, or even as a result of infinite growth of $a(t)$ in a finite time period. The former possibility realizes, e.g., in the model of a variable Λ -term based on a scalar field with a self-interaction potential $V(\phi)$ as before, but non-minimally coupled to gravity due to the term $\xi R\phi^2$ in its Lagrangian density. If $\xi > 0$ and if the field ϕ will reach the critical value $\phi_{cr} = 1/\sqrt{8\pi\xi G}$ at some finite moment of time t_{cr} in future, the effective gravitational constant G_{eff} becomes infinite, small spatial inhomogeneities grow without limit and a generic inhomogeneous space-like singularity (not oscillating) forms [15]. Very close to this singularity, the volume factor $\sqrt{-g}$ stops growing and finally approaches zero $\propto (t_{cr} - t)^q$, $0 < q < 1$, but this recollapse is strongly anisotropic.

The latter possibility takes place in an even simpler case (though not justified by a reasonable field-theoretic model) of the linear equation of state $p_\Lambda = k\varepsilon_\Lambda$, $k = const$ with $k < -1$, so that the weak energy condition $p_\Lambda + \varepsilon_\Lambda \geq 0$ is violated at the classical level. Then $a(t)$ becomes infinite (and the curvature singularity is reached) in a finite interval of time (measured from the present moment)

$$T_s = H_0^{-1} \frac{2}{3|1+k|} \int_0^1 \frac{dx}{\sqrt{1 - \Omega_m + \Omega_m x^{\frac{2|k|}{|1+k|}}}}. \quad (9)$$

As was discussed above, the Λ -term is changing sufficiently slowly, if at all. Using the supernova data, it can be shown that k should be certainly more than -1.5 . Then, taking $\Omega_m = 0.3$ and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, we obtain $T_s > 22 \text{ Gy}$. So, even for this very speculative model, we get practically the same lower bound on the period of safe expansion of Universe in future as was given before in Eq. (4).

More justified and refined field-theoretic models having such a regime which is called “superinflation”, or “pole inflation” do exist. In particular, this regime was already present among possible solutions of the higher-derivative gravity model used in [16] to construct the first viable cosmological model of the early Universe with the initial de Sitter (inflationary) stage (though, of course, another solution of this model having the “graceful exit” from inflation to the FRW radiation-dominated stage was used in this paper). Another model where pole inflation occurs is the “Pre-Big-Bang” scenario of the early Universe [17]. So, could a “Post-Big-Bang” in future be possible? Once more, I cannot exclude this possibility now.

4. Hitting a space-like singularity in future due to quantum-gravitational effects.

Finally, if none of the classical effects listed above (and other ones not known now) occurs, there always exist quantum-gravitational fluctuations. They are non-trivial (not coinciding with vacuum fluctuations in the Minkowski space-time) if $\Lambda \neq 0$. There are two kinds of them.

A. Fluctuations of an effective scalar field producing a Λ -term.

During future expansion of the Universe at the Λ -dominated stage, these fluctuations may occasionally result in jumps to a higher energy (and a higher curvature) state (“false vacuum”), in particular, even to an initial inflationary state. Depending on an effective mass of this scalar field, this transition may occur either in one jump [18], see also recent papers [19] (where this process was called “recycling of the Universe”) and [20], or as a result of a long series of small jumps, as it occurred during stochastic inflation in the early Universe [21, 22]. So, in the latter case we have “stochastic inflation in future”.

In both cases, it is necessary that the whole part of the Universe inside the de Sitter event horizon (or even a little bit larger) makes this transition. It is clear that the probability of this process is fantastically small. I don’t think that one can really grasp how small it is by his/her senses. Still it is non-zero, so this event will occur finally. This probability mainly depends on the future asymptotic value of a Λ -term $\Lambda_\infty = 3H_\infty^2$:

$$w_s \sim \exp \left(\frac{\pi}{GH_f^2} - \frac{\pi}{GH_\infty^2} \right), \quad (10)$$

where $H_f^2 = \Lambda_f/3$ is the curvature of a false vacuum state. The second term in the exponent is $\sim 10^{122}$, so it is practically impossible to imagine how large is a typical time required for this transition. However, it is finite. Thus, in this case future curvature space-like singularity is reached during continuous expansion of the Universe.

B. Quantum fluctuations of the gravitational field.

However, it appears that it is much simpler to reach future curvature singularity due to quantum fluctuations of the gravitational field itself. These fluctuations can produce a significant anisotropy described by a non-zero value of the conformal Weyl tensor comparable to that of the Riemann tensor. The corresponding quantum transition may be described by the $S_2 \times S_2$ instanton:

$$ds^2 = d\tau^2 + H_1^{-2} \sin^2 H_1 \tau \, dx^2 + H_1^{-2} d\Omega^2 = (1 - H_1^2 \tilde{x}^2) \, d\tilde{\tau}^2 + \frac{d\tilde{x}^2}{1 - H_1^2 \tilde{x}^2} + H_1^{-2} d\Omega^2, \quad (11)$$

$$d\Omega^2 = d\theta^2 + \sin^2 \theta \, d\varphi^2, \quad H_1^2 = \Lambda_\infty = 3H_\infty^2.$$

Here $\tilde{\tau}$ is a cyclic variable with the period $2\pi/H_1$. The second, “thermal” form of the instanton suggests that the transition occurs in a “local” part of the Universe with a size slightly larger than H_1^{-1} . The resulting space-time metric after the transition is:

$$ds^2 = (1 - H_1^2 \tilde{x}^2) \, d\tilde{t}^2 - \frac{d\tilde{x}^2}{1 - H_1^2 \tilde{x}^2} - H_1^{-2} d\Omega^2, \quad (12)$$

which covers a part of the Bondi-Nariai space-time [23] with a finite range of x :

$$ds^2 = dt^2 - a^2(t) \, dx^2 - b^2(t) \, d\Omega^2, \quad a(t) = H_1^{-1} \cosh H_1 t, \quad b = H_1^{-1} = \text{const}, \quad (13)$$

(see [24] for discussion of quantum-gravitational effects in the metric (13)). Note that the choice $a(t) = a_1 \exp H_1 t$ is also possible. It corresponds to covering of another part of the Bondi-Nariai space-time.

The probability of this quantum jump is given by the difference of actions for the S_4 and $S_2 \times S_2$ instantons with the same value of Λ :

$$w_g \sim \exp \left(-\frac{\pi}{GH_1^2} \right) . \quad (14)$$

Note that the exponent in Eq. (14) is 3 times less by modulus than that in Eq. (10). Thus, this second process due to purely quantum-gravitational fluctuations is much more probable, $w_s \sim w_g^3$ (though, of course, w_g is fantastically small, too).

What happens with the considered region of space-time after the jump? The space-time (13) is classically unstable with respect to long-wave gravitational perturbations ($\Lambda = \text{const}$). With the probability 0.5, b grows up and then this region returns to the locally de Sitter behaviour $a(t) \propto b(t) \propto \exp(H_\infty t)$ at $t \rightarrow \infty$ (so that the whole space-time approaches a specific form of the general quasi-de Sitter asymptote [7]). On the other hand, with the other 0.5 probability, b goes down, the region begins to recollapse soon, and the Kasner singularity $a(t) \propto (t_1 - t)^{-1/3}$, $b(t) \propto (t_1 - t)^{2/3}$ forms. Thus, this region of the Universe returns to a supercurved state.

So, one way or another, local parts of the Universe return to a singular supercurved state, though it might require a very huge amount of time. Thus, it seems at present that “cold death” is not a viable possibility for the future of our Universe. Let me emphasize that this return to a future singularity occurs in a very inhomogeneous fashion in all examples considered above. Therefore, any finite coordinate volume of the Universe becomes more and more inhomogeneous with time growth, in accordance with the Second Law of thermodynamics (understood in a very broad and imprecise sense). The same refers to the global structure of the Universe: it becomes more and more complicated in future, too. On the other hand, characteristic times for significant growth of complexity of our Universe are very large. As a result, the Universe will certainly remain very ordered for periods of the order of a few tenths of Gy that significantly exceeds its present age.

What happens after the return to a singular state? We don’t know it at the present state of the art. Still it is possible to conjecture that at least a very small part of the region which hits a singularity will bounce back and return to a low-curvature state. Especially interesting and remarkable would be if, during the process, this part spend some time at an inflationary stage. Then infinitely many low curvature and ordered universes similar to our present Universe may be created from this part in future. Repeating all this hypothetical, but not firmly prohibited process more and more, we see that the future of our Universe may be not simply *very* complicated but even *infinitely* complicated.

2 Past of the Universe

We see that discussion of the future of our Universe has naturally led us to the question of the origin of our Universe in the past, about 14 Gy ago. The preferred and very well developed

theory of a period of the evolution of the Universe preceding the hot radiation-dominated FRW stage is given by the inflationary scenario of the early Universe. According to this scenario, our Universe was in an almost maximally symmetric (de Sitter, or inflationary) state during some period of time in the past. I think that the main attractive features of the inflationary scenario are the following: 1) its extreme aesthetic elegance and beauty, and 2) complete predictability of properties of the observed part of the Universe after the end of the inflationary stage (in particular, at the present time). Thus, any concrete realization of the inflationary scenario may be falsified by observations, and many of them had been falsified already.

But it is remarkable that there exist a large class of the so called simplest inflationary models (with one slowly rolling effective scalar field producing the inflationary stage) whose predictions, just the opposite, were confirmed by observations. This especially refers to results of a COBE satellite experiment where low multipoles of the CMB angular temperature anisotropy $(\Delta T/T)_l$ with l up to ~ 20 were measured, and to results of numerous recent medium- and small-angle measurements of $\Delta T/T$ which confirm the inflationary prediction about the location and the approximate height of the so called first acoustic (Doppler) peak. So, the inflationary scenario really has a large predictive power!

Still it is clear that since any inflationary stage is not stable, but only metastable, it cannot be the *very* beginning of our Universe. Something was before, that was the origin of the inflationary stage. The most well known proposal, put forward long before the inflationary scenario was introduced in 1979-1982, was the “creation of the Universe from nothing” [25]. Here nothing means literally nothing, in particular, that were no space-time before our Universe was created. This idea does not work without some inflationary state following the creation, so it was forgotten for some time and was revived [26] only after the development of the inflationary scenario. In that case the creation is mathematically described by the S_4 (de Sitter) instanton. In the papers [25, 26] the creation of a closed FRW universe was considered, however, it was recently shown that an open FRW universe may be produced “from nothing”, too, using approximately the same (though already singular) instanton [27].

However, at the same moment the idea of “creation from nothing” was renewed, it was pointed that this is not the *only* possibility to create an inflationary stage [28]. Let me present an incomplete list of other alternatives.

1. Quasi-classical motion of space-time from a generic inhomogeneous anisotropic singularity to the de Sitter attractor solution.
2. Decay of less symmetric, higher curvature self-consistent solutions of gravity equations with all quantum corrections included (e.g., the Bondi-Nariai solution (13)).
3. Stochastic drift from a singularity with the Planckian value of curvature along a sequence of de Sitter-like solutions (this is what actually occurs in the so called eternal chaotic inflation [29]).
4. Quantum nucleation of our Universe from some other “Super-universe”, in particular, even from some asymptotically flat space-time (the latter possibility includes “creation of the Universe in a laboratory”, see [30]).
5. Creation of the Universe from a higher-dimensional space-time.

Evidently, many more possibilities remain not mentioned. It seems that they are all indistinguishable from observations. That is why, in order to tackle this great ambiguity, a completely different principle of “creation of the Universe from anything” was put forward

in [31]. Namely, it states that:

“local” observations cannot help distinguish between different ways of formation of an inflationary stage.

By “local” I mean all observations inside the presently observed Universe, and even all observations made along our future world line in arbitrary remote future. “Creation from anything” intrinsically includes all ways of creating the de Sitter (inflationary) stage, with the “creation from nothing” being only one (and therefore, scarcely probable) way among them.

It is amusing that the mathematical description of “creation from anything” is based on the same S_4 instanton as “creation from nothing”, but now written in a static, “thermal” form:

$$ds^2 = (1 - H^2 r^2) d\tau^2 + \frac{dr^2}{1 - H^2 r^2} + r^2 d\Omega^2, \quad (15)$$

where τ is periodic with the period $2\pi/H$ – the inverse Gibbons-Hawking temperature [32] (I assume here $\Lambda = \text{const} = 3H^2$ for simplicity).

Now, using the thermal interpretation of the S_4 instanton, we may ascribe the total entropy

$$S(\text{entropy}) = |S|(\text{action}) = \frac{\pi}{GH^2} \gg 1 \quad (16)$$

to the Universe at the inflationary stage. This entropy just reflects the absence of knowledge of a given observer about a space-time structure beyond the de Sitter horizon and about a way how this de Sitter stage was formed. Since $\sqrt{GH} < 10^{-5}$ at the end of an inflationary stage, $S > 10^{10}$ there.

Of course, this principle (as all principles introduced by hand) may be a little bit extreme. I cannot exclude the possibility that we shall be able to get some knowledge about a pre-inflationary history of our Universe. Then a value of the entropy of the Universe at the end of an inflationary stage will be less than that given by Eq. (16).

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